FERMILAB-POSTER-23-209-STUDENT

Design of a Nanophotonic Hybrid Coupler

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Problem of Interest

- LAr scintillation light: 128 nm [1]
- LXe scintillation light: 175 nm [1]

(LAr and LXe scintillation light are both vacuum ultraviolet: 10-200 nm.)

- Current VUV photodetectors have low efficiencies [1, 2]
- Wavelength shifters down covert VUV light to a longer wavelength [1]
- Light needs to be focused and enhanced to allow better detection [3]
- Metalens: nanostructured surfaces used to manipulate light [4]
- Purpose: design a hybrid (plasmonic-dielectric) coupler that has wavelength shifting properties and can achieve partial far-field radiation control and high Purcell enhancement

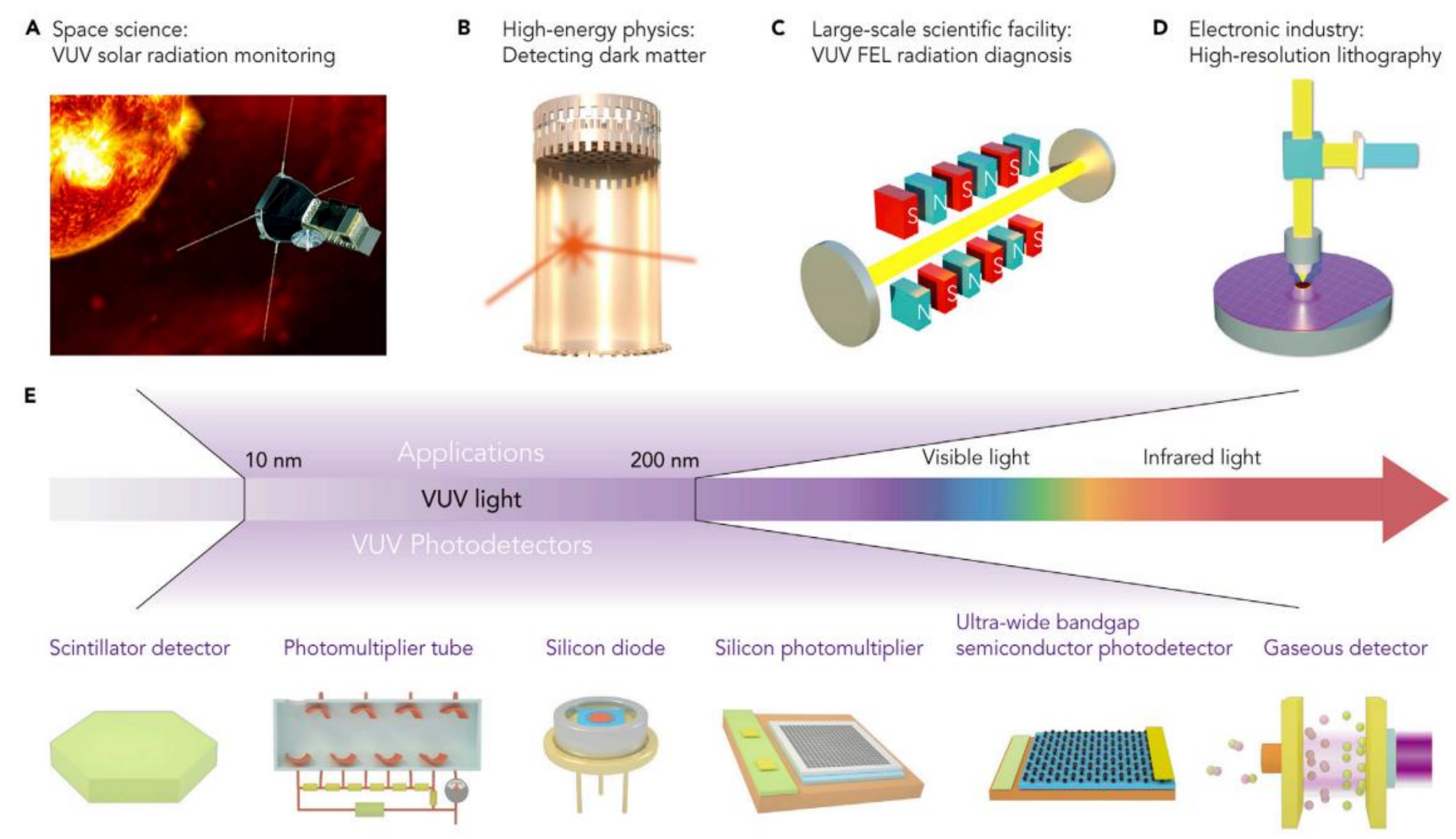

Figure 1: Examples of the applications of VUV photodetectors [2].

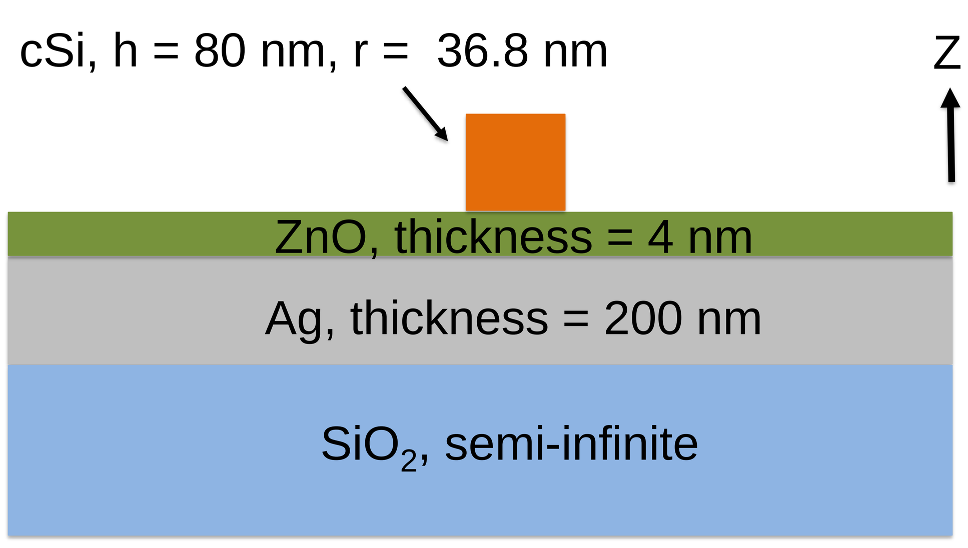

Figure 2: Schematic of the plasmonic-dielectric coupler.

Solution

- A cylindrical cSi resonator for field confinement
- A ZnO layer as an intrinsic wavelength shifter (excited by VUV light and emit at ~390 nm) [5]
  - A Z-oriented electric dipole source with an offset of 27.2 nm
- Ag and SiO_2 substrate
- Advantages of plasmonics: high local fields and Purcell enhancement [3]
- Advantages of dielectrics: low absorption loss [3]

Methods

- Finite-difference time domain (FDTD) method for Maxwell's equations
- Meep: an open-source package scriptable in Python, Scheme, C++ [6]
- Lumerical: a commercial photonic simulation software [7]

Results and Conclusions

- Purcell factor reaches a maximum (~10^4) near 390 nm (Figure 3)
  - Enhancement of spontaneous emission rate due to environment [8]
  - Ratio of power emitted in a specific environment to power emitted in a homogenous environment [8]
- Partial control of the far-field radiation (Figure 4)
  - Without the resonator: radiation going sideways
  - With the resonator: radiation directed towards the coupled metalens
- Future: further optimization of the coupler, design of the metalens

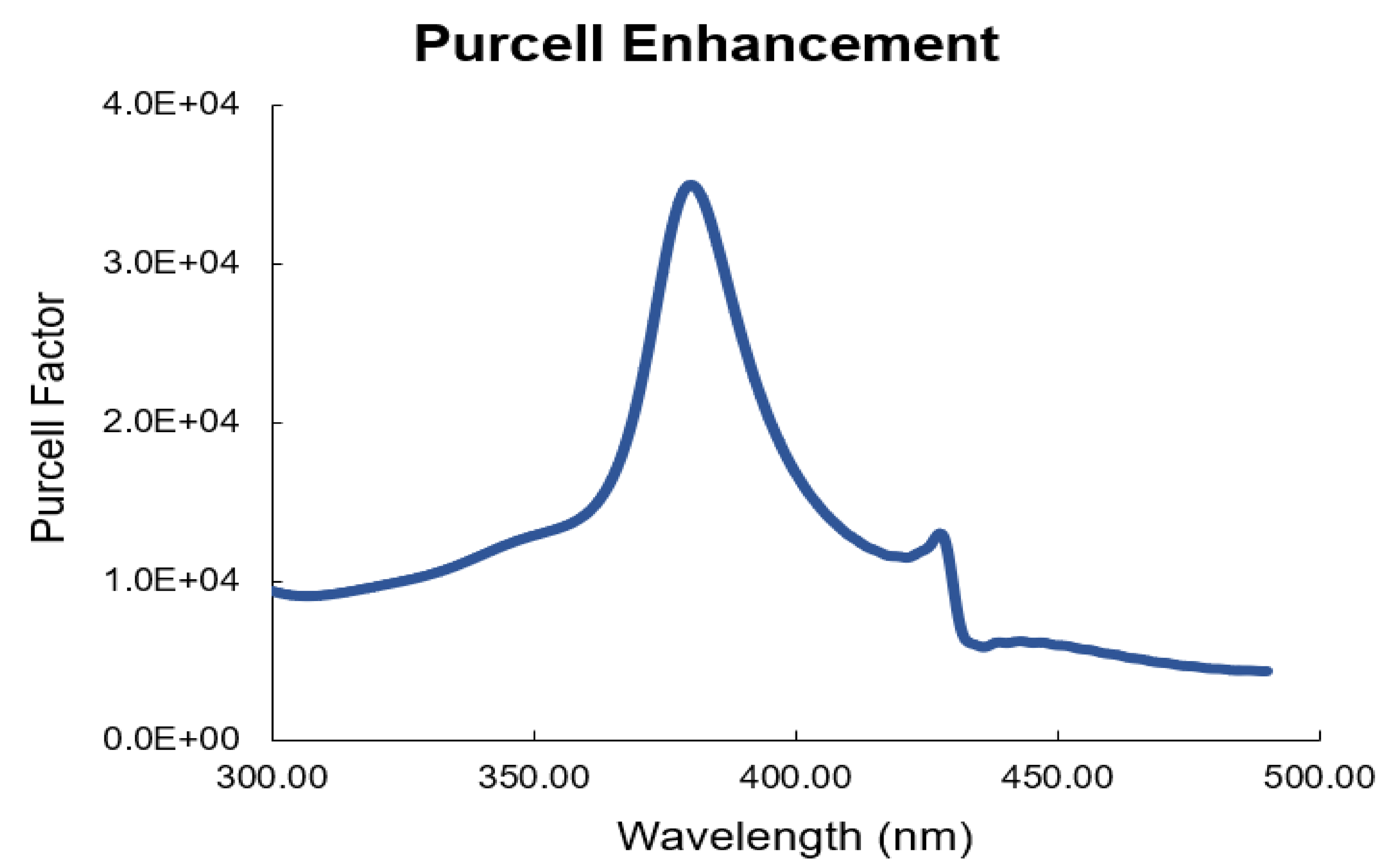

Figure 3: Plot of the Purcell factor as a function of wavelength.

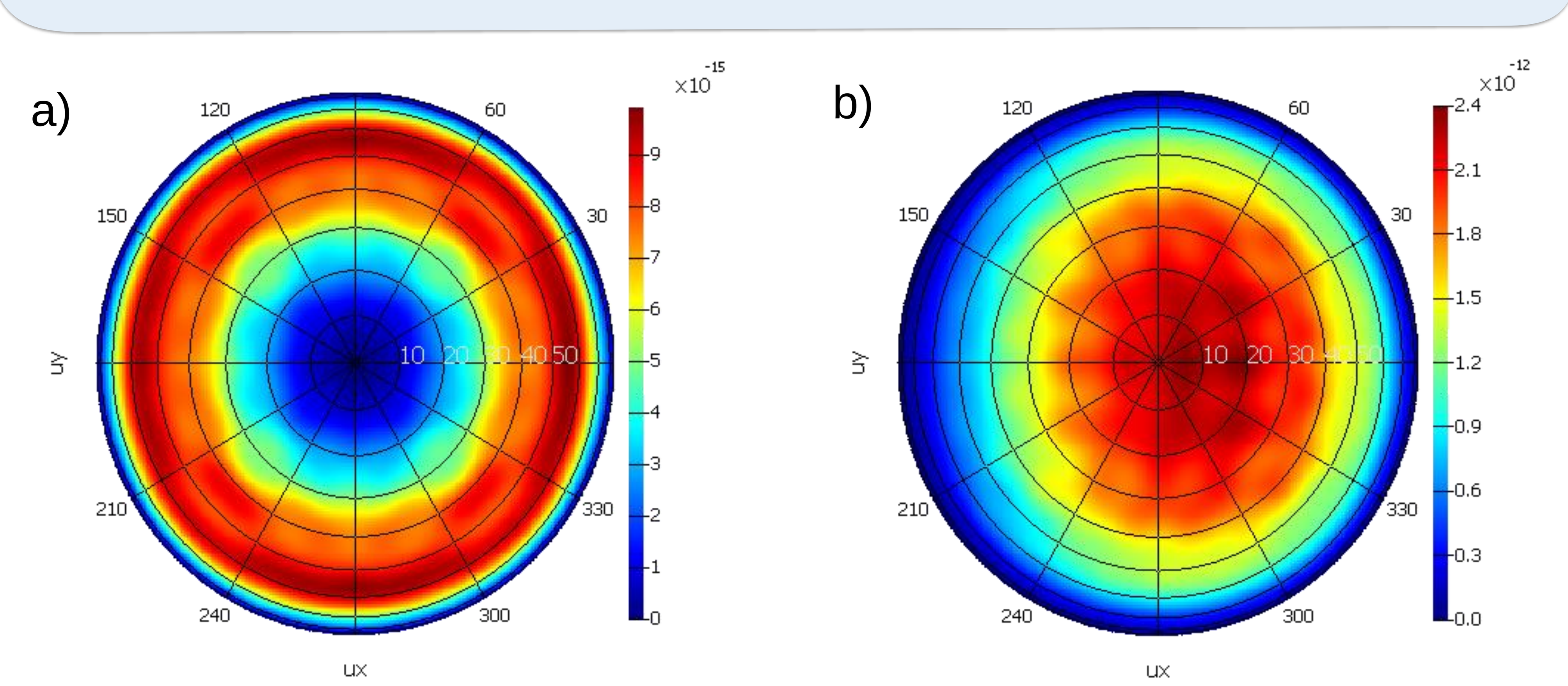

Figure 4: Far-field radiation plots a) without and b) with the resonator.

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References

[1] M. Kuźniak and A. M. Szelc, Instr. **5**, 4 (2021). [2] W. Zheng, L. Jia, and F. Huang, iScience **23**, 101145 (2020). [3] F. Yang, et al., J. Appl. Phys. **130**, 163103 (2021). [4] S. Liu, et al., Nano Lett. **18** (2018). [5] M. J. F. Empizo, et al., Opt. Mat. **65** (2017). [6] A. F. Oskooi, et al., Comp. Phys. Comm. **181**, 3 (2010). [7] Lumerical Inc., FDTD: 3D Electromagnetic Simulator. [8] A. E. Krasnok, et al., Sci. Rep. **5**, 12956 (2015).